Chemistry

First examinations 2009

Diploma Programme

Data booklet

Diploma Programme

Chemistry
Data booklet

First examinations 2009

International Baccalaureate Organization

Buenos Aires Cardiff Geneva New York Singapore

Diploma Programme
Chemistry—data booklet

Published March 2007

International Baccalaureate Organization
Peterson House, Malthouse Avenue, Cardiff Gate
Cardiff, Wales GB CF23 8GL
United Kingdom
Phone: +44 29 2054 7777
Fax: +44 29 2054 7778
Web site: http://www.ibo.org

The International Baccalaureate Organization (IBO) was established in 1968 and is a non-profit, international educational foundation registered in Switzerland.

IBO merchandise and publications in its official and working languages can be purchased through the IB store at http://store.ibo.org. General ordering queries should be directed to the sales and marketing department in Cardiff.

Phone: +44 29 2054 7746
Fax: +44 29 2054 7779
E-mail: sales@ibo.org

Printed in the United Kingdom by Antony Rowe Ltd, Chippenham, Wiltshire

Contents

Notes
This booklet cannot be used for paper 1 of the examination (SLP1 and HLP1), but the periodic table given on page 4 will be available as part of these examination papers. Clean copies of this booklet must be made available to candidates for papers 2 and 3 (SLP2, SLP3, HLP2 and HLP3).

1. Some relevant equations

$$t_{\frac{1}{2}} = \frac{0.693}{k}$$

$$\log_{10}\frac{I_0}{I} = \varepsilon lc$$

$$k = Ae^{\frac{-E_a}{RT}}$$

$$\ln k = -\frac{E_a}{RT} + \ln A$$

$$E = hf$$

$$PV = nRT$$

$$\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$$

2. Physical constants

Avogadro's constant (L) = 6.02×10^{23} mol^{-1}

Gas constant (R) = 8.31 J K^{-1} mol^{-1}

Molar volume of an ideal gas at 273 K and 1.01×10^5 Pa = 2.24×10^{-2} m^3 mol^{-1} (= 22.4 dm^3 mol^{-1})

Planck's constant (h) = 6.63×10^{-34} J s

Specific heat capacity of water = 4.18 kJ kg^{-1} K^{-1} (= 4.18 J g^{-1} K^{-1})

Ionic product constant for water (K_w) = 1.00×10^{-14} mol^2 dm^{-6} at 298 K

1 atm = 1.01×10^5 Pa

1 dm^3 = 1 litre = 1×10^{-3} m^3 = 1×10^3 cm^3

3. Fundamental particles

	Proton	Neutron	Electron
Mass (kg)	1.672648×10^{-27}	1.674954×10^{-27}	9.109534×10^{-31}
Charge (C)	1.602189×10^{-19}	0	1.602189×10^{-19}

4. Names of the first 103 elements

Element	Symbol	Atomic number	Element	Symbol	Atomic number
actinium	Ac	89	fluorine	F	9
aluminium	Al	13	francium	Fr	87
americium	Am	95	gadolinium	Gd	64
antimony	Sb	51	gallium	Ga	31
argon	Ar	18	germanium	Ge	32
arsenic	As	33	gold	Au	79
astatine	At	85	hafnium	Hf	72
barium	Ba	56	helium	He	2
berkelium	Bk	97	holmium	Ho	67
beryllium	Be	4	hydrogen	H	1
bismuth	Bi	83	indium	In	49
boron	B	5	iodine	I	53
bromine	Br	35	iridium	Ir	77
cadmium	Cd	48	iron	Fe	26
caesium	Cs	55	krypton	Kr	36
calcium	Ca	20	lanthanum	La	57
californium	Cf	98	lawrencium	Lr	103
carbon	C	6	lead	Pb	82
cerium	Ce	58	lithium	Li	3
chlorine	Cl	17	lutetium	Lu	71
chromium	Cr	24	magnesium	Mg	12
cobalt	Co	27	manganese	Mn	25
copper	Cu	29	mendelevium	Md	101
curium	Cm	96	mercury	Hg	80
dysprosium	Dy	66	molybdenum	Mo	42
einsteinium	Es	99	neodymium	Nd	60
erbium	Er	68	neon	Ne	10
europium	Eu	63	neptunium	Np	93
fermium	Fm	100	nickel	Ni	28

Element	Symbol	Atomic number	Element	Symbol	Atomic number
niobium	Nb	41	silicon	Si	14
nitrogen	N	7	silver	Ag	47
nobelium	No	102	sodium	Na	11
osmium	Os	76	strontium	Sr	38
oxygen	O	8	sulfur	S	16
palladium	Pd	46	tantalum	Ta	73
phosphorus	P	15	technetium	Tc	43
platinum	Pt	78	tellurium	Te	52
plutonium	Pu	94	terbium	Tb	65
polonium	Po	84	thallium	Tl	81
potassium	K	19	thorium	Th	90
praseodymium	Pr	59	thulium	Tm	69
promethium	Pm	61	tin	Sn	50
protactinium	Pa	91	titanium	Ti	22
radium	Ra	88	tungsten	W	74
radon	Rn	86	uranium	U	92
rhenium	Re	75	vanadium	V	23
rhodium	Rh	45	xenon	Xe	54
rubidium	Rb	37	ytterbium	Yb	70
ruthenium	Ru	44	yttrium	Y	39
samarium	Sm	62	zinc	Zn	30
scandium	Sc	21	zirconium	Zr	40
selenium	Se	34			

5. The periodic table

1	2											3	4	5	6	7	0
1 **H** 1.01				Atomic number **Element** Atomic mass													2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.90	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.71	29 **Cu** 63.55	30 **Zn** 65.37	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** 98.91	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.40	49 **In** 114.82	50 **Sn** 118.69	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.30
55 **Cs** 132.91	56 **Ba** 137.34	57 † **La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.85	75 **Re** 186.21	76 **Os** 190.21	77 **Ir** 192.22	78 **Pt** 195.09	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.37	82 **Pb** 207.19	83 **Bi** 208.98	84 **Po** (210)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 ‡ **Ac** (227)															

†	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** 146.92	62 **Sm** 150.35	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.92	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.04	71 **Lu** 174.97
‡	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (254)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)

6. Melting points and boiling points of the elements

14 **H** 20				Melting point (K) **Element** Boiling point (K)													1 **He** 4
454 **Li** 1600	1551 **Be** 3243											2573 **B** 3931	4100 **C** 5100	63 **N** 77	55 **O** 90	54 **F** 85	25 **Ne** 27
371 **Na** 1156	922 **Mg** 1363											936 **Al** 2740	1683 **Si** 2628	317 **P** 553	392 **S** 718	172 **Cl** 239	84 **Ar** 87
337 **K** 1047	1112 **Ca** 1757	1814 **Sc** 3104	1933 **Ti** 3560	1973 **V** 3650	2130 **Cr** 2755	1517 **Mn** 2235	1808 **Fe** 3023	1768 **Co** 3143	1726 **Ni** 3005	1357 **Cu** 2840	693 **Zn** 1180	303 **Ga** 2676	1211 **Ge** 3103	1090 **As** 886	490 **Se** 958	266 **Br** 332	117 **Kr** 121
312 **Rb** 961	1042 **Sr** 1657	1780 **Y** 3611	2125 **Zr** 4650	2741 **Nb** 5015	2890 **Mo** 4885	2445 **Tc** 5150	2583 **Ru** 4173	2239 **Rh** 4000	1825 **Pd** 3413	1235 **Ag** 2485	594 **Cd** 1038	429 **In** 2353	505 **Sn** 2543	904 **Sb** 2023	723 **Te** 1263	387 **I** 458	161 **Xe** 166
302 **Cs** 952	983 **Ba** 2023	1194 **La** 3730	2503 **Hf** 5470	3269 **Ta** 5698	3680 **W** 5930	3453 **Re** 5900	3327 **Os** 5300	2683 **Ir** 4403	2045 **Pt** 4100	1338 **Au** 3080	234 **Hg** 630	577 **Tl** 1730	601 **Pb** 2013	545 **Bi** 1833	527 **Po** 1235	575 **At** 610	202 **Rn** 211
300 **Fr** 950	973 **Ra** 1413	1320 **Ac** 3470															

7. First ionization energy, electron affinity and electronegativity of the elements

1310 –72 **H** 2.1																	2370 **He**
519 –52 **Li** 1.0	900 **Be** 1.5											799 –29 **B** 2.0	1090 –120 **C** 2.5	1400 –3 **N** 3.0	1310 –142 (O^- +844) **O** 3.5	1680 –348 **F** 4.0	2080 **Ne**
494 –71 **Na** 0.9	736 **Mg** 1.2											577 –47 **Al** 1.5	786 –180 **Si** 1.8	1060 –70 **P** 2.1	1000 –200 (S^- +532) **S** 2.5	1260 –364 **Cl** 3.0	1520 **Ar**
418 **K** 0.8	590 **Ca** 1.0	632 **Sc** 1.3	661 **Ti** 1.5	648 **V** 1.6	653 **Cr** 1.6	716 **Mn** 1.5	762 **Fe** 1.8	757 **Co** 1.8	736 **Ni** 1.8	745 **Cu** 1.9	908 **Zn** 1.6	577 **Ga** 1.6	762 **Ge** 1.8	966 **As** 2.0	941 **Se** 2.4	1140 –342 **Br** 2.8	1350 **Kr**
402 **Rb** 0.8	548 **Sr** 1.0	636 **Y** 1.2	669 **Zr** 1.4	653 **Nb** 1.6	694 **Mo** 1.8	699 **Tc** 1.9	724 **Ru** 2.2	745 **Rh** 2.2	803 **Pd** 2.2	732 **Ag** 1.9	866 **Cd** 1.7	556 **In** 1.7	707 **Sn** 1.8	833 **Sb** 1.9	870 **Te** 2.1	1010 –314 **I** 2.5	1170 **Xe**
376 **Cs** 0.7	502 **Ba** 0.9	540 **La** 1.1	531 **Hf** 1.3	760 **Ta** 1.5	770 **W** 1.7	762 **Re** 1.9	841 **Os** 2.2	887 **Ir** 2.2	866 **Pt** 2.2	891 **Au** 2.4	1010 **Hg** 1.9	590 **Tl** 1.8	716 **Pb** 1.8	703 **Bi** 1.9	812 **Po** 2.0	920 **At** 2.2	1040 **Rn**
381 **Fr** 0.7	510 **Ra** 0.9	669 **Ac** 1.1															

First ionization energy (kJ mol^{-1}) | Electron affinity (kJ mol^{-1})

Element

Electronegativity

8. Atomic and ionic radii of the elements

30 **H** 154 (1–)																**He**
152 **Li** 68 (1+)	112 **Be** 30 (2+)											88 **B** 16 (3+)	77 **C** 260 (4–)	70 **N** 171 (3–)	66 **O** 146 (2–)	58 **F** 133 (1–)	**Ne**
186 **Na** 98 (1+)	160 **Mg** 65 (2+)											143 **Al** 45 (3+)	117 **Si** 42 (4+) 271 (4–)	110 **P** 212 (3–)	104 **S** 190 (2–)	99 **Cl** 181 (1–)	**Ar**
231 **K** 133 (1+)	197 **Ca** 94 (2+)	160 **Sc** 81 (3+)	146 **Ti** 90 (2+) 68 (4+)	131 **V** 88 (2+) 59 (5+)	125 **Cr** 63 (3+)	129 **Mn** 80 (2+) 60 (4+)	126 **Fe** 76 (2+) 64 (3+)	125 **Co** 74 (2+) 63 (3+)	124 **Ni** 72 (2+)	128 **Cu** 96 (1+) 69 (2+)	133 **Zn** 74 (2+)	141 **Ga** 62 (3+)	122 **Ge** 53 (4+) 272 (4–)	121 **As** 222 (3–)	117 **Se** 202 (2–)	114 **Br** 196 (1–)	**Kr**
244 **Rb** 148 (1+)	215 **Sr** 110 (2+)	180 **Y** 93 (3+)	157 **Zr** 80 (4+)	141 **Nb** 70 (5+)	136 **Mo** 68 (4+)	135 **Tc**	133 **Ru** 65 (4+)	134 **Rh** 86 (2+)	138 **Pd**	144 **Ag** 126 (1+)	149 **Cd** 97 (2+)	166 **In** 81 (3+)	162 **Sn** 112 (2+) 71 (4+)	141 **Sb** 245 (3–)	137 **Te** 222 (2–)	133 **I** 219 (1–)	**Xe**
262 **Cs** 167 (1+)	217 **Ba** 34 (2+)	188 **La** 115 (3+)	157 **Hf** 81 (4+)	143 **Ta** 73 (5+)	137 **W** 68 (4+)	137 **Re**	134 **Os** 67 (4+)	135 **Ir** 66 (4+)	138 **Pt**	144 **Au** 137 (1+) 85 (3+)	152 **Hg** 127 (1+) 110 (2+)	171 **Tl** 95 (3+)	175 **Pb** 120 (2+) 84 (4+)	170 **Bi** 120 (3+)	140 **Po**	140 **At**	**Rn**
270 **Fr**	220 **Ra**	200 **Ac**															

Atomic radius (10^{-12} m)

Element

Ionic radius (10^{-12} m)

9. Covalent bond lengths

Bond	Bond length (nm)	Bond	Bond length (nm)
H–H	0.074	C–H	0.109
C–C	0.154	Si–H	0.146
C=C	0.134	N–H	0.101
C≡C	0.120	P–H	0.142
C–C (in benzene)	0.139	O–H	0.096
Si–Si	0.235	S–H	0.135
N–N	0.146	F–H	0.092
N=N	0.120	Cl–H	0.128
N≡N	0.110	Br–H	0.141
P–P (P_4)	0.221	I–H	0.160
O–O	0.148	C–O	0.143
O=O	0.121	C=O	0.122
S–S (S_8)	0.207	C–O (in phenol)	0.136
S=S	0.188	C–N	0.147
F–F	0.142	C=N	0.127
Cl–Cl	0.199	C≡N	0.116
Br–Br	0.228	C–N (in phenylamine)	0.135
I–I	0.267	C–F	0.138
		C–Cl	0.177
		C–Cl (in chlorobenzene)	0.169
		C–Br	0.193
		C–I	0.214
		Si–O	0.150

10. Average bond enthalpies at 298 K

Bond	ΔH (kJ mol^{-1})	Bond	ΔH (kJ mol^{-1})
H–H	436	C–H	412
D–D	442	Si–H	318
C–C	348	N–H	388
C=C	612	P–H	322
C≡C	837	O–H	463
C–C (benzene)	518	S–H	338
Si–Si	226	F–H	562
Ge–Ge	188	Cl–H	431
Sn–Sn	151	Br–H	366
N–N	163	I–H	299
N=N	409	C–O	360
N≡N	944	C=O	743
P–P	172	C–N	305
O–O	146	C=N	613
O=O	496	C≡N	890
S–S	264	C–F	484
F–F	158	C–Cl	338
Cl–Cl	242	C–Br	276
Br–Br	193	C–I	238
I–I	151	Si–O	374

11. Organic compounds—thermodynamic data

Substance	Formula	State	$\Delta H_f^\ominus$ (kJ mol^{-1})	$\Delta G_f^\ominus$ (kJ mol^{-1})	$S^\ominus$ (J K^{-1} mol^{-1})
methane	CH_4	g	–75	–51	186
ethane	C_2H_6	g	–85	–33	230
propane	C_3H_8	g	–104	–24	270
butane	C_4H_{10}	g	–125	–16	310
pentane	C_5H_{12}	l	–173	–9	261
hexane	C_6H_{14}	l	–199	–4	296
ethene	C_2H_4	g	52	68	219
propene	C_3H_6	g	20	63	267
but-1-ene	C_4H_8	g	1	72	307
cis-but-2-ene	C_4H_8	g	–6	67	301
trans-but-2-ene	C_4H_8	g	–10	64	296
ethyne	C_2H_2	g	227	209	201
propyne	C_3H_4	g	185	194	248
buta-1,3-diene	C_4H_6	g	112	152	279
cyclohexane	C_6H_{12}	l	–156	27	204
benzene	C_6H_6	g	83	130	269
benzene	C_6H_6	l	49	125	173
methylbenzene	$C_6H_5CH_3$	l	12	111	320
ethylbenzene	$C_6H_5CH_2CH_3$	l	13	120	255
phenylethene	$C_6H_5CHCH_2$	l	104	202	345
chloromethane	CH_3Cl	g	–82	–59	234
dichloromethane	CH_2Cl_2	l	–117	–63	179
trichloromethane	$CHCl_3$	l	–132	–72	203
bromomethane	CH_3Br	g	–36	–26	246
tribromomethane	$CHBr_3$	l	–20	3	222
iodomethane	CH_3I	l	–8	20	163
triiodomethane	CHI_3	s	141		
chloroethane	C_2H_5Cl	g	–105	–53	276
bromoethane	C_2H_5Br	l	–85		

Substance	Formula	State	$\Delta H_f^\ominus$ (kJ mol^{-1})	$\Delta G_f^\ominus$ (kJ mol^{-1})	$S^\ominus$ (J K^{-1} mol^{-1})
iodoethane	C_2H_5I	l	–31		
chloroethene	C_2H_3Cl	g	31	52	264
1,2-dichloroethane	CH_2ClCH_2Cl	l	–166	–80	208
chlorobenzene	C_6H_5Cl	l	11	94	314
methanol	CH_3OH	g	–201	–162	238
methanol	CH_3OH	l	–239	–166	127
ethanol	C_2H_5OH	g	–235	–169	282
ethanol	C_2H_5OH	l	–278	–175	161
phenol	C_6H_5OH	s	–163	–51	146
methanal	HCHO	g	–116	–110	219
ethanal	CH_3CHO	g	–166	–134	266
propanone	$(CH_3)_2CO$	l	–216	–152	295
methanoic acid	HCOOH	l	–409	–346	129
ethanoic acid	CH_3COOH	l	–487	–392	160
benzoic acid	C_6H_5COOH	s	–385	–245	167
ethyl ethanoate	$CH_3COOC_2H_5$	l	–481		
ethanamide	CH_3CONH_2	s	–320		
methylamine	CH_3NH_2	g	–28	28	242
ethylamine	$C_2H_5NH_2$	g	–49	37	285
urea	$CO(NH_2)_2$	s	–333	–47	105

12. Enthalpies of combustion

The values of the molar enthalpy of combustion $(\Delta H_c^{\ominus})$ in the following table refer to a temperature of 298 K and a pressure of 1.01×10^5 Pa (1 atm).

Substance	Formula	State	$\Delta H_c^{\ominus}$ (kJ mol^{-1})	Substance	Formula	State	$\Delta H_c^{\ominus}$ (kJ mol^{-1})
hydrogen	H_2	g	–286	propan-1-ol	C_3H_7OH	l	–2010
sulfur	S	s	–297	butan-1-ol	C_4H_9OH	l	–2673
carbon (graphite)	C	s	–394	phenylmethanol	$C_6H_5CH_2OH$	l	–4056
carbon (diamond)	C	s	–395	cyclohexanol	$C_6H_{11}OH$	s	–3727
carbon monoxide	CO	g	–283	phenol	C_6H_5OH	s	–3064
methane	CH_4	g	–890	ethoxyethane	$(C_2H_5)_2O$	l	–2727
ethane	C_2H_6	g	–1560	methanal	HCHO	g	–561
propane	C_3H_8	g	–2220	ethanal	CH_3CHO	l	–1167
butane	C_4H_{10}	g	–2877	benzaldehyde	C_6H_5CHO	l	–3520
pentane	C_5H_{12}	g	–3509	propanone	$(CH_3)_2CO$	l	–1786
hexane	C_6H_{14}	l	–4194	pentan-3-one	$(C_2H_5)_2CO$	l	–3078
octane	C_8H_{18}	l	–5512	phenylethanone	$CH_3COC_6H_5$	s	–4138
cyclohexane	C_6H_{12}	l	–3924	diphenylmethanone	$(C_6H_5)_2CO$	s	–6512
ethene	C_2H_4	l	–1409	methanoic acid	HCOOH	l	–263
buta-1,3-diene	C_4H_6	g	–2542	ethanoic acid	CH_3COOH	l	–876
ethyne	C_2H_2	g	–1299	benzoic acid	C_6H_5COOH	s	–3227
benzene	C_6H_6	l	–3267	ethanedioic acid	$(COOH)_2$	s	–246
methylbenzene	$C_6H_5CH_3$	l	–3909	ethyl ethanoate	$CH_3COOC_2H_5$	l	–2246

Substance	Formula	State	$\Delta H_c^\ominus$ (kJ mol^{-1})	Substance	Formula	State	$\Delta H_c^\ominus$ (kJ mol^{-1})
naphthalene	$C_{10}H_8$	l	–5157	ethanamide	CH_3CONH_2	s	–1182
anthracene	$C_{14}H_{10}$	s	–7114	benzamide	$C_6H_5CONH_2$	s	–3546
chloroethane	C_2H_5Cl	g	–1413	methylamine	CH_3NH_2	g	–1072
bromoethane	C_2H_5Br	l	–1425	ethylamine	$C_2H_5NH_2$	g	–1709
iodoethane	C_2H_5I	l	–1466	phenylamine	$C_6H_5NH_2$	l	–3397
(chloromethyl)benzene	$C_6H_5CH_2Cl$	l	–3709	nitrobenzene	$C_6H_5NO_2$	l	–3094
trichloromethane	$CHCl_3$	l	–373	urea	$CO(NH_2)_2$	s	–634
methanol	CH_3OH	l	–715	glucose	$C_6H_{12}O_6$	s	–2816
ethanol	C_2H_5OH	l	–1371	sucrose	$C_{12}H_{22}O_{11}$	s	–5644

13. Lattice enthalpies at 298 K (experimental and theoretical values)

The lattice enthalpy values ($\Delta H^{\ominus}_{\text{lattice}}$) given relate to the endothermic process

$MX(s) \rightarrow M^{+}(g) + X^{-}(g)$

in which the gaseous ions of a crystal are separated to an infinite distance from each other.

Experimental values

The data in these two tables are experimental values obtained by means of a suitable Born–Haber cycle.

Alkali metal halides	$\Delta H^{\ominus}_{\text{lattice}}$ (kJ mol^{-1})			
	F	Cl	Br	I
Li	1022	846	800	744
Na	902	771	733	684
K	801	701	670	629
Rb	767	675	647	609
Cs	716	645	619	585

Other substances	$\Delta H^{\ominus}_{\text{lattice}}$ (kJ mol^{-1})	Other substances	$\Delta H^{\ominus}_{\text{lattice}}$ (kJ mol^{-1})
CaF_2	2602	MgS	3238
$BeCl_2$	3006	CaS	2966
$MgCl_2$	2493	SrS	2779
$CaCl_2$	2237	BaS	2643
$SrCl_2$	2112	CuCl	976
$BaCl_2$	2018	AgF	955
MgO	3889	AgCl	905
CaO	3513	AgBr	890
SrO	3310	AgI	876
BaO	3152	NH_4Cl	640

Theoretical values

These two tables contain lattice enthalpies calculated from electrostatic principles on the basis of a purely ionic model for the crystal.

Alkali metal halides	$\Delta H^{\ominus}_{\text{lattice}}$ (kJ mol^{-1})			
	F	Cl	Br	I
Li	1004	833	787	728
Na	891	766	732	686
K	795	690	665	632
Rb	761	674	644	607
Cs	728	636	611	582

Other substances	$\Delta H^{\ominus}_{\text{lattice}}$ (kJ mol^{-1})	Other substances	$\Delta H^{\ominus}_{\text{lattice}}$ (kJ mol^{-1})
CaF_2	2611	AgF	870
MgO	3929	AgCl	770
CaO	3477	AgBr	758
SrO	3205	AgI	736
BaO	3042		

14. Standard electrode potentials

Oxidized species	⇌	Reduced species	$E^{\ominus}$ (V)
$Li^+(aq) + e^-$	⇌	$Li(s)$	–3.03
$K^+(aq) + e^-$	⇌	$K(s)$	–2.92
$Ca^{2+}(aq) + 2e^-$	⇌	$Ca(s)$	–2.87
$Na^+(aq) + e^-$	⇌	$Na(s)$	–2.71
$Mg^{2+}(aq) + 2e^-$	⇌	$Mg(s)$	–2.36
$Al^{3+}(aq) + 3e^-$	⇌	$Al(s)$	–1.66
$Mn^{2+}(aq) + 2e^-$	⇌	$Mn(s)$	–1.18
$H_2O(l) + e^-$	⇌	$\frac{1}{2}H_2(g) + OH^-(aq)$	–0.83
$Zn^{2+}(aq) + 2e^-$	⇌	$Zn(s)$	–0.76
$Fe^{2+}(aq) + 2e^-$	⇌	$Fe(s)$	–0.44
$Ni^{2+}(aq) + 2e^-$	⇌	$Ni(s)$	–0.23
$Sn^{2+}(aq) + 2e^-$	⇌	$Sn(s)$	–0.14
$Pb^{2+}(aq) + 2e^-$	⇌	$Pb(s)$	–0.13
$H^+(aq) + e^-$	⇌	$\frac{1}{2}H_2(g)$	0.00
$Cu^{2+}(aq) + e^-$	⇌	$Cu^+(aq)$	+0.15
$SO_4^{2-}(aq) + 4H^+(aq) + 2e^-$	⇌	$H_2SO_3(aq) + H_2O(l)$	+0.17
$Cu^{2+}(aq) + 2e^-$	⇌	$Cu(s)$	+0.34
$\frac{1}{2}O_2(g) + H_2O(l) + 2e^-$	⇌	$2OH^-(aq)$	+0.40
$Cu^+(aq) + e^-$	⇌	$Cu(s)$	+0.52

Oxidized species	⇌	Reduced species	$E^{\ominus}$ (V)
$\frac{1}{2}I_2(s) + e^-$	⇌	$I^-(aq)$	+0.54
$Fe^{3+}(aq) + e^-$	⇌	$Fe^{2+}(aq)$	+0.77
$Ag^+(aq) + e^-$	⇌	$Ag(s)$	+0.80
$\frac{1}{2}Br_2(l) + e^-$	⇌	$Br^-(aq)$	+1.09
$\frac{1}{2}O_2(g) + 2H^+(aq) + 2e^-$	⇌	$H_2O(l)$	+1.23
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^-$	⇌	$2Cr^{3+}(aq) + 7H_2O(l)$	+1.33
$\frac{1}{2}Cl_2(g) + e^-$	⇌	$Cl^-(aq)$	+1.36
$MnO_4^-(aq) + 8H^+(aq) + 5e^-$	⇌	$Mn^{2+}(aq) + 4H_2O(l)$	+1.51
$\frac{1}{2}F_2(g) + e^-$	⇌	$F^-(aq)$	+2.87

15. Strengths of organic acids and bases

The acid strengths in the following tables are given in terms of pK_a values, where p$K_a = -\log_{10} K_a$.

The dissociation constant, K_a, values are for aqueous solutions at 298 K. Base strengths are given in terms of pK_b values.

Carboxylic acids

Name	Formula	pK_a
methanoic	$HCOOH$	3.75
ethanoic	CH_3COOH	4.76
propanoic	CH_3CH_2COOH	4.87
butanoic	$CH_3(CH_2)_2COOH$	4.82
2-methylpropanoic	$(CH_3)_2CHCOOH$	4.85
pentanoic	$CH_3(CH_2)_3COOH$	4.86
2,2-dimethylpropanoic	$(CH_3)_3CCOOH$	5.05
benzoic	C_6H_5COOH	4.20
phenylethanoic	$C_6H_5CH_2COOH$	4.31

Halogenated carboxylic acids

Name	Formula	pK_a
chloroethanoic	$CH_2ClCOOH$	2.86
dichloroethanoic	$CHCl_2COOH$	1.29
trichloroethanoic	CCl_3COOH	0.65
fluoroethanoic	CH_2FCOOH	2.66
bromoethanoic	$CH_2BrCOOH$	2.90
iodoethanoic	CH_2ICOOH	3.17

Phenols

Name	Formula	pK_a
phenol	C_6H_5OH	10.00
2-nitrophenol	$O_2NC_6H_4OH$	7.21
3-nitrophenol	$O_2NC_6H_4OH$	8.35
4-nitrophenol	$O_2NC_6H_4OH$	7.15
2,4-dinitrophenol	$(O_2N)_2C_6H_3OH$	4.01
2,4,6-trinitrophenol	$(O_2N)_3C_6H_2OH$	0.42

Alcohols

Name	Formula	pK_a
methanol	CH_3OH	15.5
ethanol	C_2H_5OH	16.0

Amines

Name	Formula	pK_b
ammonia	NH_3	4.75
methylamine	CH_3NH_2	3.36
ethylamine	$CH_3CH_2NH_2$	3.27
dimethylamine	$(CH_3)_2NH$	3.28
trimethylamine	$(CH_3)_3N$	4.20
diethylamine	$(C_2H_5)_2NH$	3.07
triethylamine	$(C_2H_5)_3N$	3.36
phenylamine	$C_6H_5NH_2$	9.38

16. Acid–base indicators

			Colour change	
Indicator	pK_a	pH range	Acid	Alkali
methyl orange	3.7	3.1–4.4	red	yellow
bromophenol blue	4.0	3.0–4.6	yellow	blue
bromocresol green	4.7	3.8–5.4	yellow	blue
methyl red	5.1	4.2–6.3	red	yellow
bromothymol blue	7.0	6.0–7.6	yellow	blue
phenol red	7.9	6.8–8.4	yellow	red
phenolphthalein	9.3	8.3–10.0	colourless	red

17. Infrared data

Characteristic ranges for infrared absorption due to stretching vibrations in organic molecules.

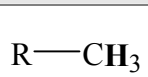
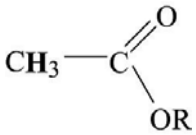
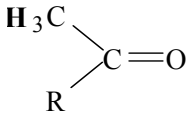
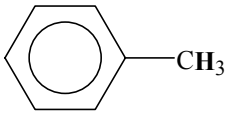
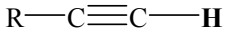
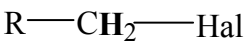
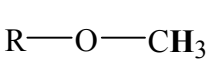
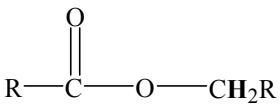
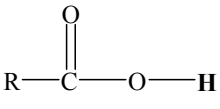
Bond	Organic molecules	Wavenumber (cm^{-1})
C–I	iodoalkanes	490–620
C–Br	bromoalkanes	500–600
C–Cl	chloroalkanes	600–800
C–F	fluoroalkanes	1000–1400
C–O	alcohols, esters, ethers	1050–1410
C=C	alkenes	1610–1680
C=O	aldehydes, ketones, acids, esters	1700–1750
C≡C	alkynes	2100–2260
O–H	“hydrogen bonded” in acids	2500–3300
C–H	alkanes, alkenes, arenes	2850–3100
O–H	“hydrogen bonded” in alcohols, phenols	3200–3600
N–H	primary amines	3300–3500

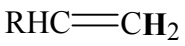
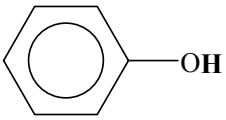
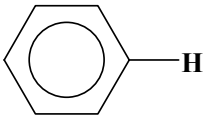
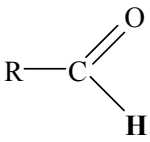
18. ^{1}H NMR data

Typical proton chemical shift values (δ) relative to tetramethylsilane (TMS) = 0.

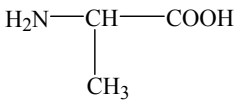
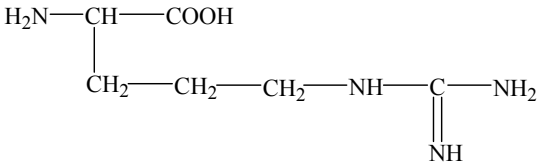
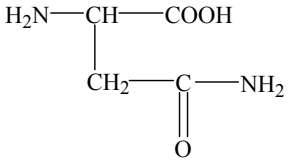
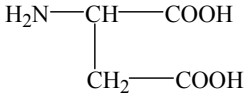
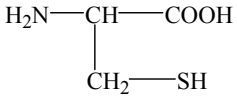
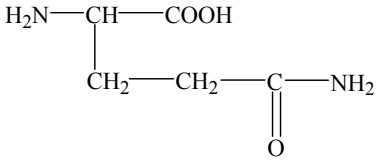
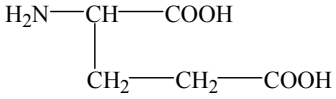
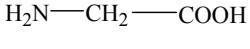
R represents an alkyl group, and Hal represents F, Cl, Br, or I.

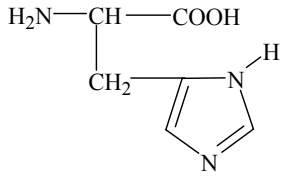
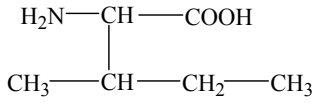
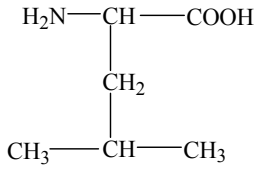
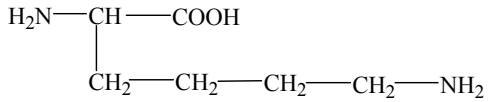
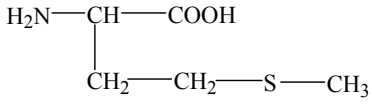
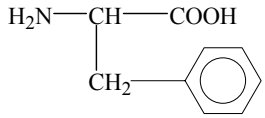
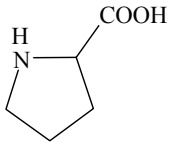
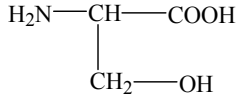
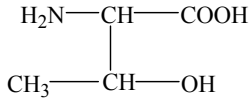
These values may vary in different solvents and conditions.

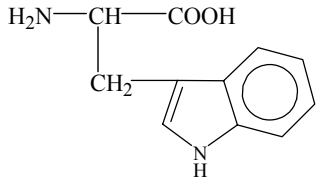
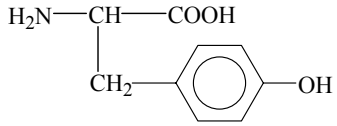
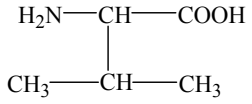
Type of proton	Chemical shift (ppm)
	0.9–1.0
	1.3–1.4
	1.4–1.6
	2.0–2.5
	2.2–2.7
	2.5–3.5
	1.8–3.1
	3.5–4.4
	3.3–3.7
	3.8–4.1
	9.0–13.0
	4.0–12.0

Type of proton	Chemical shift (ppm)
	4.5–6.0
	4.0–12.0
	6.9–9.0
	9.4–10.0

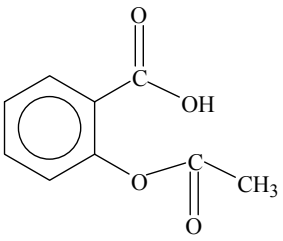
19. 2-Amino acids

Common name	Symbol	Structural formula	pH of isoelectric point
alanine	Ala		6.0
arginine	Arg		10.8
asparagine	Asn		5.4
aspartic acid	Asp		2.8
cysteine	Cys		5.1
glutamine	Gln		5.7
glutamic acid	Glu		3.2
glycine	Gly		6.0

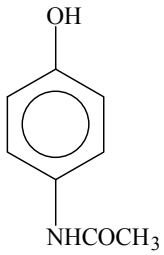
Common name	Symbol	Structural formula	pH of isoelectric point
histidine	His		7.6
isoleucine	Ile		6.0
leucine	Leu		6.0
lysine	Lys		9.7
methionine	Met		5.7
phenylalanine	Phe		5.5
proline	Pro		6.3
serine	Ser		5.7
threonine	Thr		5.6

Common name	Symbol	Structural formula	pH of isoelectric point
tryptophan	Trp		5.9
tyrosine	Tyr		5.7
valine	Val		6.0

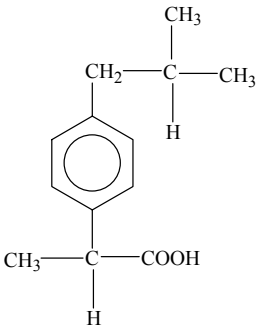
20. Structural formulas of some important medicines and drugs



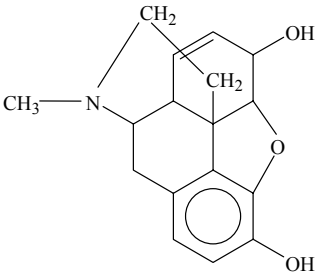
aspirin



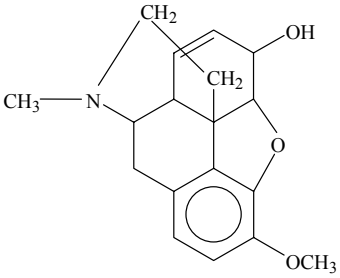
paracetamol
(acetaminophen)



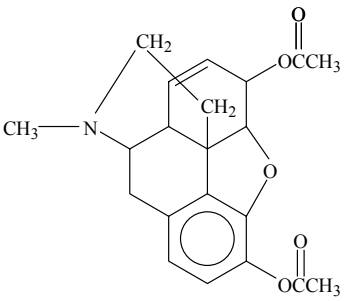
ibuprofen



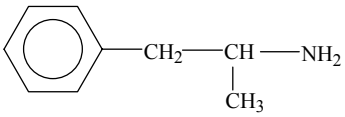
morphine



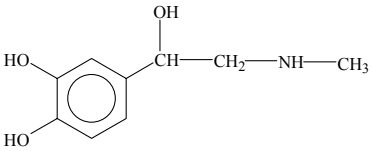
codeine



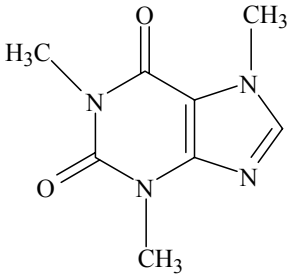
heroin



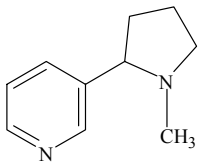
amphetamine



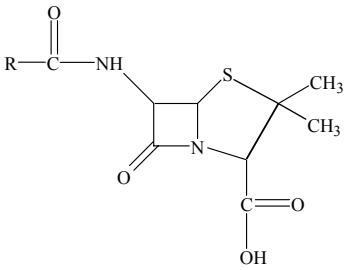
epinephrine (adrenaline)



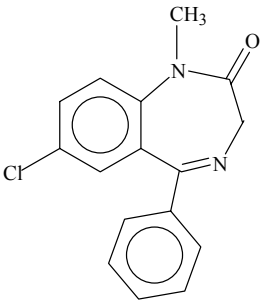
caffeine



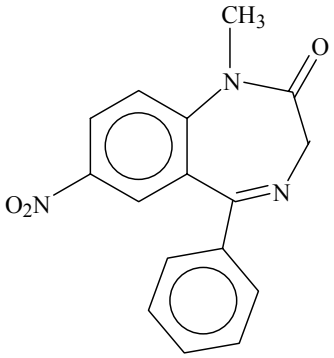
nicotine



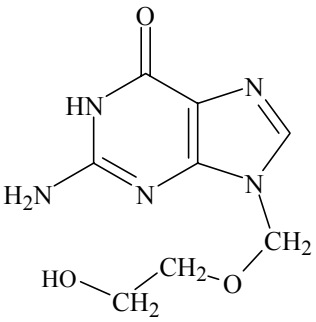
penicillin



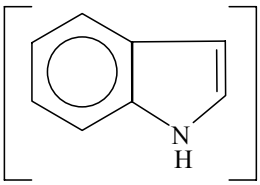
diazepam (Valium®)



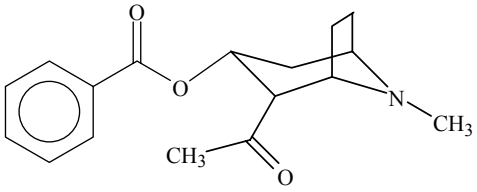
nitrazepam (Mogadon®)



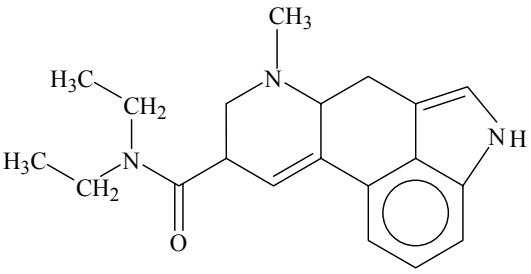
acyclovir



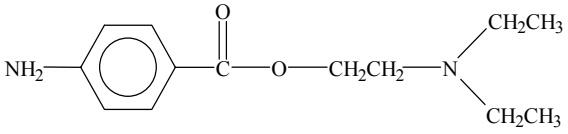
indole



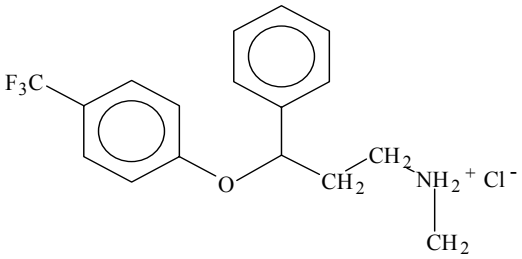
cocaine



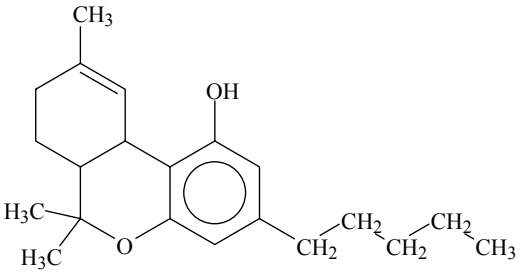
lysergic acid diethylamide (LSD)



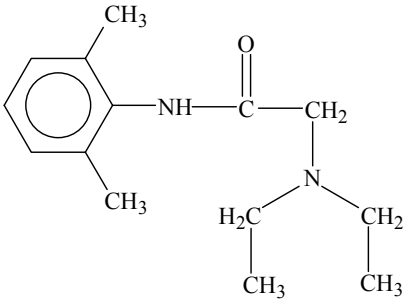
procaine



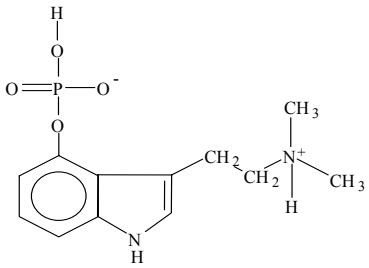
fluoxetine hydrochloride (Prozac®)



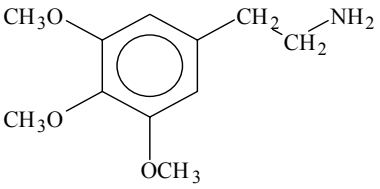
tetrahydrocannabinol (THC)



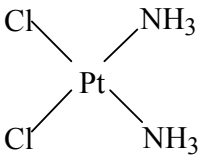
lidocaine



psilocybine

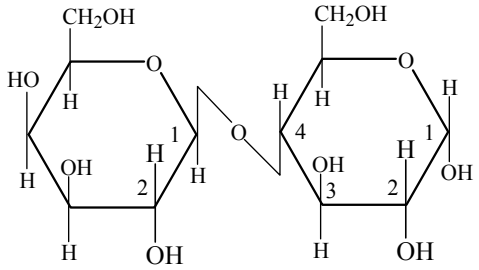


mescaline

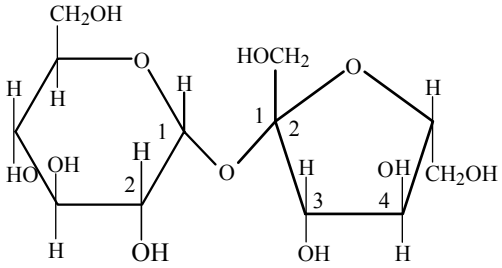


cisplatin

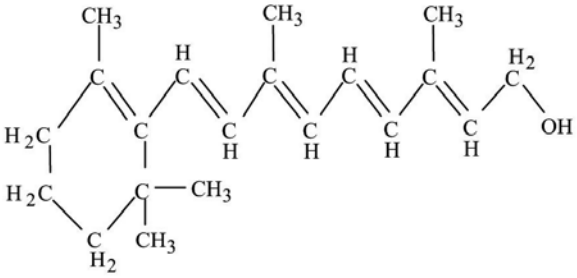
21. Structural formulas of some important biological molecules



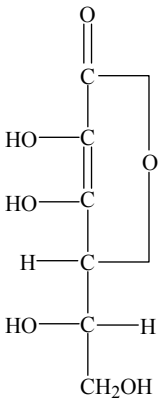
lactose



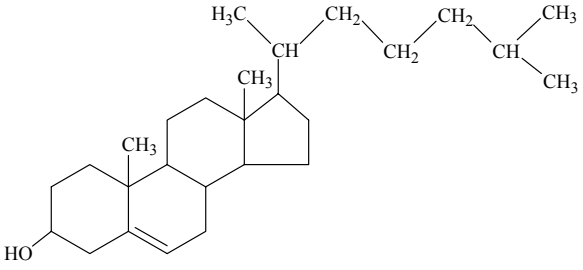
sucrose



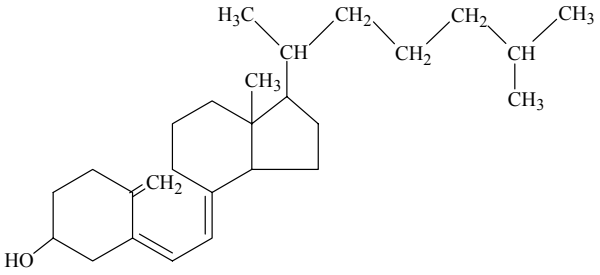
retinol (vitamin A)



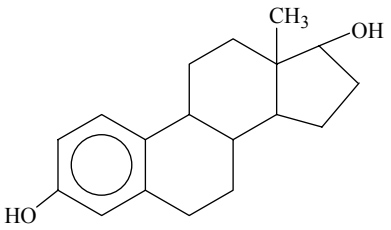
ascorbic acid (vitamin C)



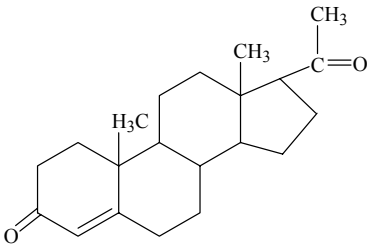
cholesterol



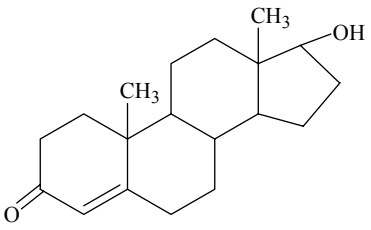
vitamin D



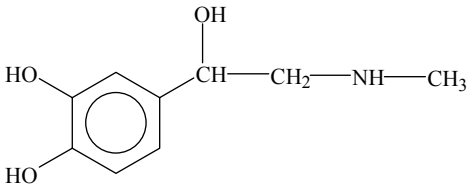
estradiol



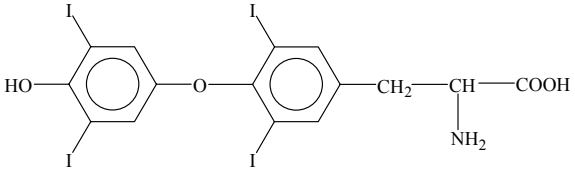
progesterone



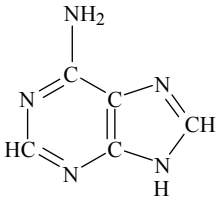
testosterone



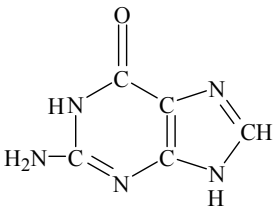
epinephrine (adrenaline)



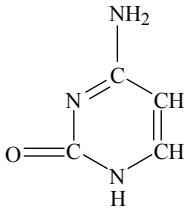
thyroxine



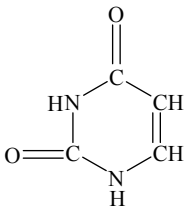
adenine



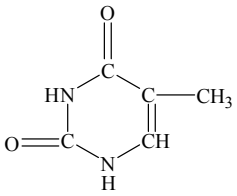
guanine



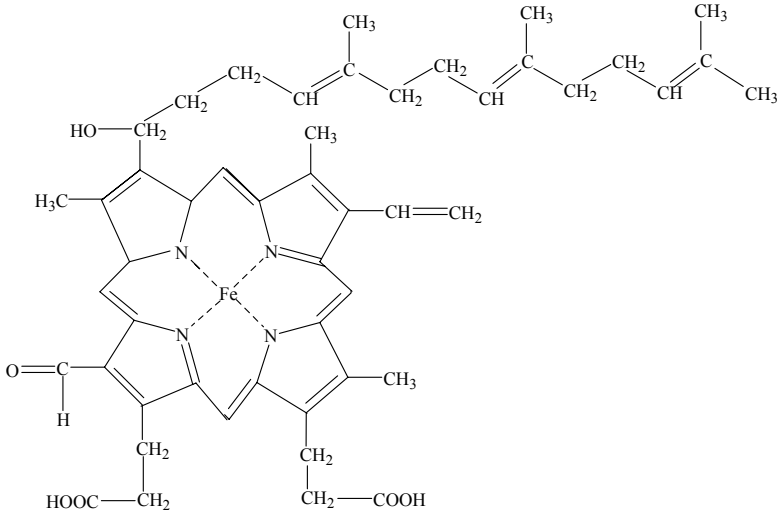
cytosine



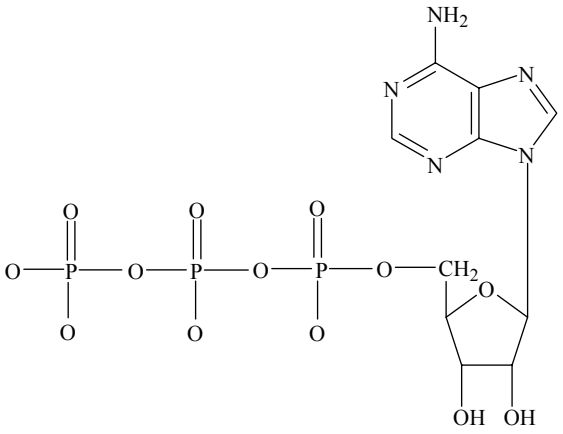
uracil



thymine



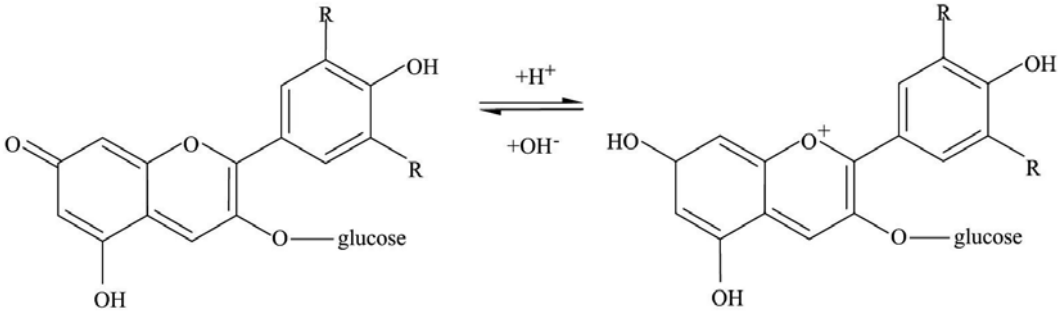
the heme group from cytochrome oxidase



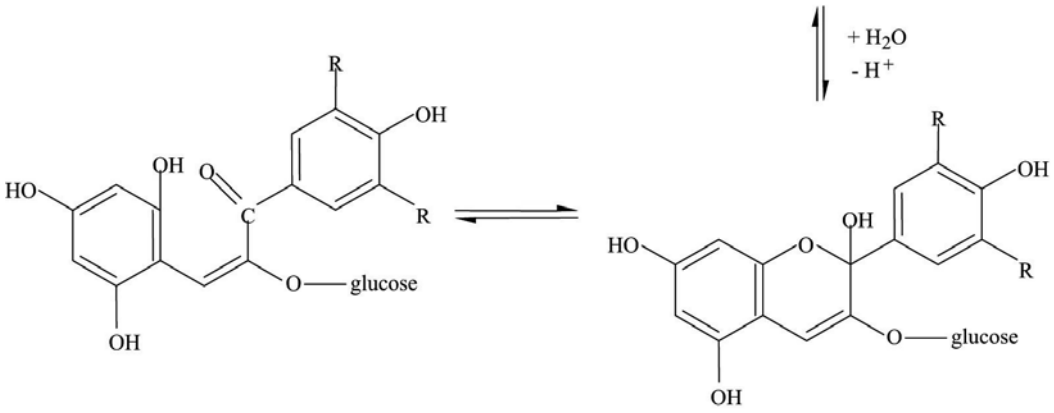
adenosine triphosphate (ATP)

22. Structural formulas of some important food chemistry molecules

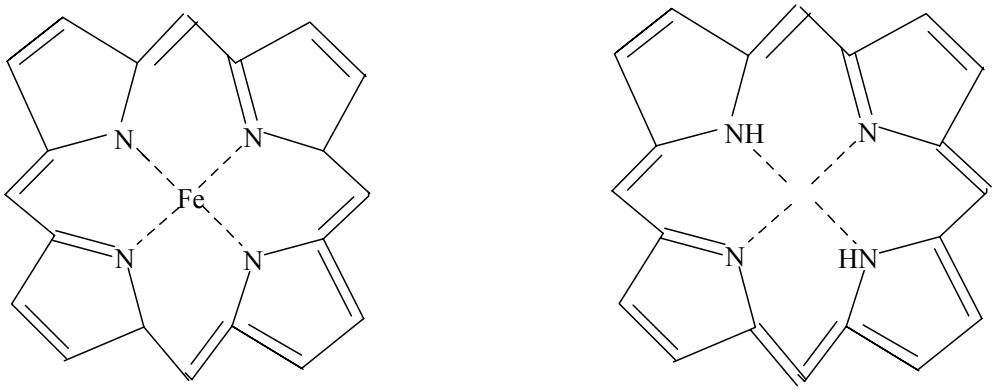
Some anthocyanins



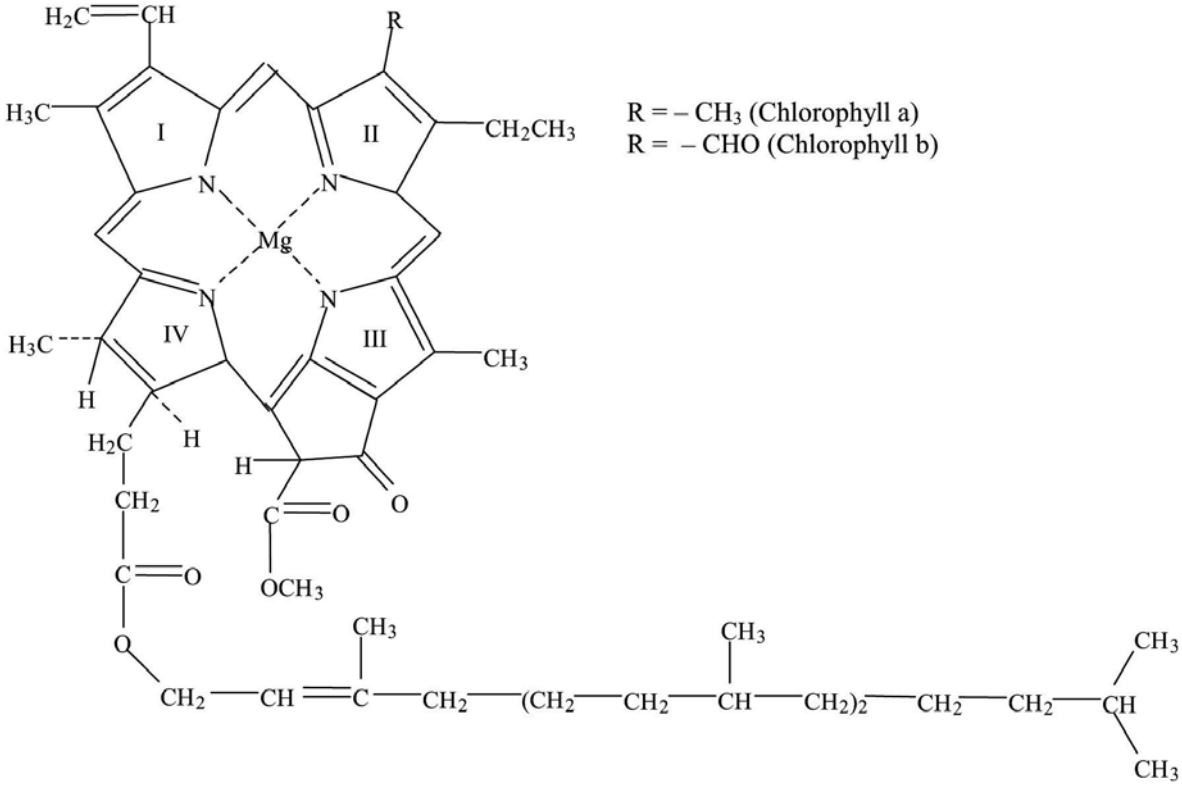
quinoidal base (blue) flavylium cation (red)



chalcone (colourless) carbinol pseudo-base (colourless)

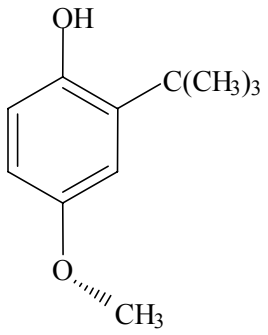


myoglobin porphyrin

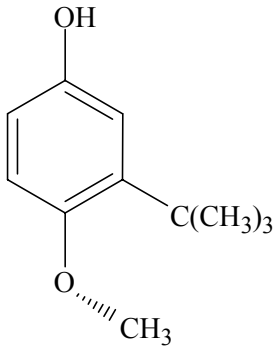


chlorophyll

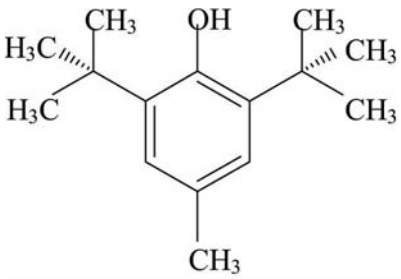
Some preservatives



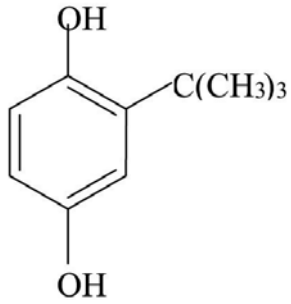
2-*tert*-butyl-4-hydroxyanisole (2-BHA)



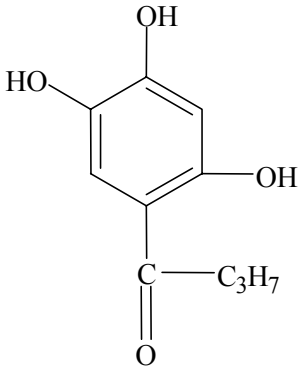
3-*tert*-butyl-4-hydroxyanisole (3-BHA)



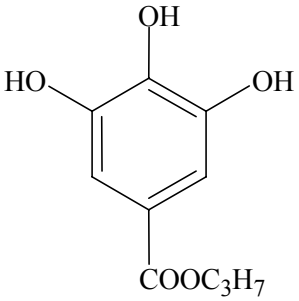
3,5-di-*tert*-butyl-4-hydroxytoluene (BHT)



tert-butylhydroquinone (TBHQ)

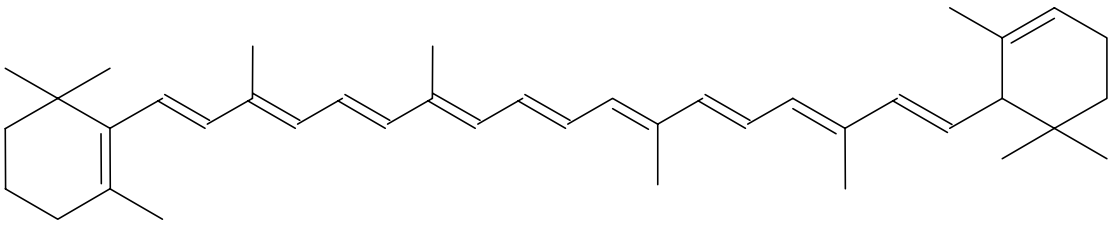


2,4,5-trihydroxybutyrophenone (THBP)

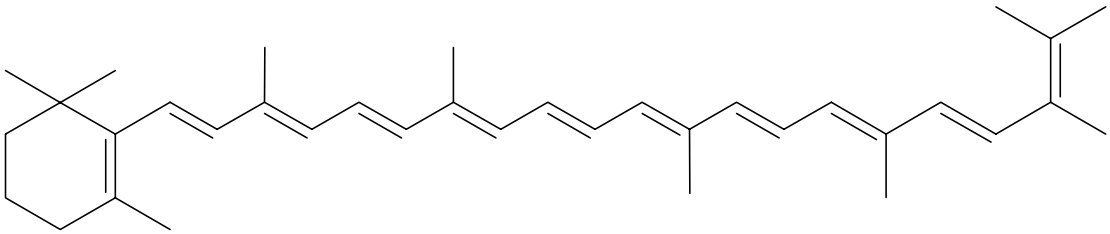


propyl gallate (PG)

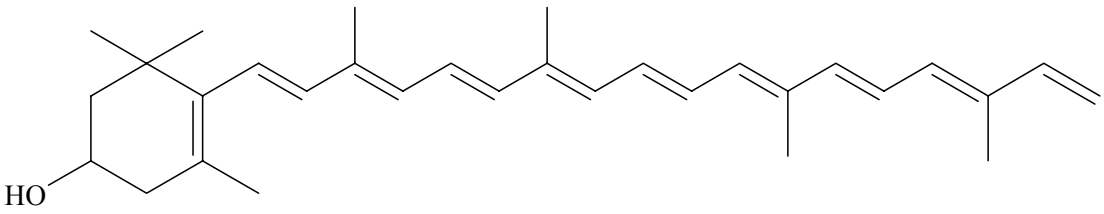
Some of the carotenes



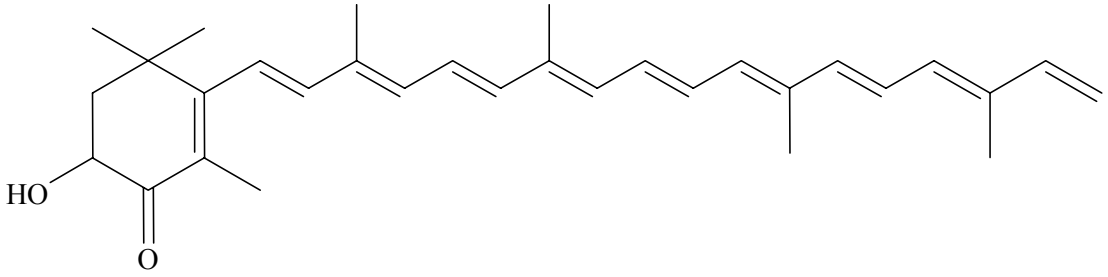
alpha-carotene



beta-carotene



lutein



astaxanthin

Some fatty acids

Fatty acid	Formula
Octanoic acid	$CH_3(CH_2)_6COOH$
Lauric acid	$CH_3(CH_2)_{10}COOH$
Stearic acid	$CH_3(CH_2)_{14}COOH$
Palmitic acid	$CH_3(CH_2)_{14}COOH$
Oleic acid	$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$
Linoleic acid	$CH_3(CH_2)_4(CH{=}CHCH_2)_2(CH_2)_6COOH$
Linolenic acid	$CH_3CH_2(CH{=}CHCH_2)_3(CH_2)_6COOH$